DOCUMENT RESUME

ED 394 849 SE 058 381

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TITLE	Viewing the Roots of Technology and Science: A Philosophical and Historical View.
PUB DATE	Jan 96
NOTE	7p.; Paper presented at the Jerusalem International Science and Technology Education Conference (2nd, Jerusalem, Israel, January 8-11, 1996).
PUB TYPE	Viewpoints (Opinion/Position Papers, Essays, etc.) (120) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Elementary Secondary Education; Foreign Countries; Higher Education; Philosophy; *Science History; *Technology
IDENTIFIERS	Australia

ABSTRACT

This paper emphasizes the historical and philosophical roots of science and technology. It addresses questions about the origins of science with its emphasis on knowing, understanding, and explaining aspects of the human world and the origins of technology with its focus on using materials and tools to design and make artifacts of value. A case study of a single technological artifact is used to illustrate the argument that technology is not simply applied science, that the relationship between the two fields is complex, and its nature has changed over the course of history. It is argued that technological knowledge is necessary for the growth of subsequent scientific knowledge. (JRH)

Symposium 1.
Viewing the Roots of Technology and Science:
A Philosophical and Historical View

by

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SYMPOSIUM 1:

VIEWING THE ROOTS OF TECHNOLOGY AND SCIENCE

A PHILOSOPHICAL AND HISTORICAL VIEW

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Address given at JISTEC'96, the Second Jerusalem International Science and Technology Education Conference, Jerusalem, 8-11 January 1996.

What are the historical and philosophical roots of science and technology? How did these great human enterprises originate: science, with its emphasis on knowing, understanding and explaining aspects of the natural world, and technology, with its focus on using materials and tools to design and make artefacts of value?

In some ways, these are old questions. For a conference being held in *Yerushalayim, ir hakodesh*, Jerusalem, the Holy City, it will perhaps not be considered out of place if I quote an extract from the *Pirke Avoth*, the Sayings of the Fathers, written about 1800 years ago. The book is a compilation of popular teachings of the Rabbinic Sages. It deals with many themes: how to behave correctly, how to act wisely, how to achieve true piety. The writing is gentle and humane, wise and profound, and imbued with poetic imagery.

One saying offers an explanation for the origins of a simple technology. In Chapter V, verse 9, the Rabbis are discussing the last things created by the Almighty on the sixth day of Creation, just before the onset of the first Sabbath. The verse lists various things, such as writing, and the tablets of stone on which the Ten Commandments were to be written. The verse ends, *v'yesh omrim af tz'vat bitzvat asuyah:* "and some say the tongs made with tongs". Clearly, the rabbis knew that a blacksmith needed a pair of tongs to hold the hot metal in order to make a new set of tongs on the anvil. If every pair of tongs needs a prior pair of tongs, then, they obviously wondered, how were the very first set of tongs made?

We are modern and sophisticated scholars, and we are probably inclined to smile at this explanation and accept it as a charming myth, an imaginative fragment of creative prose, without taking it literally. And yet, if we probe beneath the surface, there is an important question here. How did not only the tongs but also the millions of other artefacts, materials and systems that constitute our modern technological world originate?

A common answer to this question reflects an idealist view of human culture. The idealist view emphasises thought as a basis for practical action, science as the foundation stone for technology. A 1962 book on my shelf, W.S. Fowler's *The Development of Scientific Method*, exemplifies this view. According to this story-line, the roots of modern science are to be found in ancient Greek philosophy, in the early atomic ideas of

Democritus, in Plato's belief in the importance of mathematical reasoning as the gateway to truth and knowledge, in Aristotle's doctrine of the four causes, in Epicurus's emphasis on rationality in place of superstition. In the early sections of this book, technology is hardly mentioned; when it is, as in the example of Archimedes' screw for raising water, it is described as a development in practical physics. Fowler goes on to mention the role of Arabic mathematicians and astronomers in preserving scholarship during the Dark Ages. Roger Bacon's *Magnum Opus* is mentioned with its argument that practical experience of the world and not simply logical reasoning was necessary for acquiring knowledge, but this appeal to practical experience was essentially a call to observe nature carefully. Fowler's book then moves on to the Copernican Revolution, to the contribution of Francis Bacon in emphasising experimental method and to the development of modern science in the 17th and 18th centuries. Here again, the few technological illustrations are presented as products of scientific thought: the electric battery as a consequence of Galvani and Volta's experiments. The dynamo is credited to Ampere and Faraday's studies of electricity and magnetism.

In this reading of the history of science and technology, much is made of a distinctive characteristic of the human species, namely our capacity for language and thought, our ability to conceptualise and reason, our skill at using concepts as a basis for action. If we follow this line of argument through, it leads to an explanation of our technological world as an outcome of human thought. Human beings interact with objects and materials in the world, they become experienced with them, they think about things, and they make new things. Go to the Bible Lands Museum not far from here and you will see flint knives and stone axes made tens of thousands of years ago by the early dwellers in the Jordan Valley. Or visit a modern materials science research facility where the latest ceramics are being developed. Between the two, there is a long gap in time and a considerable difference in sophistication, but the motivation and the approach — to use resources intelligently to meet human needs — is surely the same.

However, a problem arises with this account when some people — often scientists or historians of science — want to equate human thought with scientific thought. This leads to a view of technology as an outcome of science. Scientists do research, the argument runs, and technologists apply this knowledge for practical ends. Technological fruits fall from scientific trees. This is a widespread and dominant view, and one can often find it expressed in science curriculum documents and textbooks. We have become easily conditioned to accept this view of technology as the application of scientific ideas. The idea is appealing and it is easy to point to numerous examples during the past century and a half to support it. Look at modern chemistry, or electrical engineering, or atomic physics. The chemical industry which began to flourish a century ago rests upon a foundation of research by the chemists in the preceding century. Voltaic cells, current electricity, magnetism and electromagnetism, the work of Galvani and Volta and Ohm and Ampere and Faraday, provided the intellectual underpinnings for the emergence of the giant enterprise which today we call electrical engineering. Roentgen's discovery of X-rays quickly led to their practical application in medical diagnosis, and later in metallurgy and materials science.

Nevertheless, I want to argue that as a general description, this account is simplistic, and over most of human history, basically untrue. During the past thirty years, various philosophers, historians and engineers — the names of Don Ihde, Eugene Ferguson, Cyril

Stanley Smith, Walter Vincenti, Otto Mayr, Edwin Layton and Ronald Kline come to mind — have done much to overturn this superficially attractive but fundamentally incorrect view. Technology is **not** simply applied science. The relationship between the two fields is complex, and its nature has changed over the course of history. Both science and technology have their origins in the world of the practical: in the insights of the artist, in the skill of the artisan, in the capabilities of the engineer.

Since it is impossible to give a complete study of the historical and philosophical roots of science and technology in only twenty minutes — it usually takes me at least an hour — I thought I would offer a small case study of a single technological artefact to illustrate my argument. The artefact is right here before you: the overhead projector I am using. I hope the machine does not become schizophrenic as I use it simultaneously as an object of study and as a tool to display itself and other artefacts.

(OHP of OHP)
Consider what the overhead projector does: it displays enlarged images of a transparency on a screen. Clearly this artefact has evolved from the earlier slide projector and a similar device called an epidiascope used to project images of book pages on a screen. I use the term 'evolved' deliberately, to parallel the process of biological evolution. Artefacts are almost never developed *ab initio*: their inventors invariably draw upon a long line of earlier designs, often combined in new ways to perform new functions for different social purposes. The slide projector was itself a development of the nineteenth century magic lantern, originally conceived as a toy for the amusement of children. It was developed during a time when children were no longer regarded simply as miniature adults, but as people with their own specific needs, interests and pleasures. As the historian Lewis Mumford has pointed out, artefacts develop in response to social values and cultural demands. Except for the photocopier which I used to make this transparency, there is nothing in principle which prevented the overhead projector from being made a century ago. It is a common artefact now because educators now value visual as well as verbal input and because wealthy societies can afford to purchase educational technology for their schools. My point here is that some of the roots of technology are to be found in cultural and economic considerations, in what is wanted as well as what is possible.

The overhead projector is a technological **system**, an integrated set of various component parts. Consider its optical components. Some of the technological roots of this machine are quite ancient. The notion of throwing images on to a screen is an old idea, dating back to the *camera obscura* of ancient Greek times. The mirror up here which allows me to face you while the machine throws an image behind me is even older: small polished-metal hand-mirrors were known in ancient times, although the modern metal-backed glass mirror is a later invention, first appearing in the late 12th century. The mirror in this machine is, however, front-silvered, not back-silvered: I will let you reflect on the reason for this design feature. The mirror serves another function: it allows both of us to see the picture right side up, unlike a slide projector, which inverts the image. This is not a particularly novel technological innovation: in Renaissance times, artists used portable camera obscuras containing an angled mirror for viewing their subjects and tracing their outlines, right-side-up, on to paper.

(OHP of ankh)
Many different materials have been used to make this device: glass, metal, plastic. There are several glass components in the optical system; let us spend a few moments reviewing the history of this crucial material. This Egyptian ceramic ornament, an ankh, is about 3500 years old. It is an early example of faience, earthenware coated with a glass-like material made from powdered quartz fused with an alkali-rich material. Two thousand years ago, the Romans made clear glass for windows and household containers. In medieval times, jewellers were fashioning lens-shaped ornaments, and one could imagine that these served as objects whose effects on light caught the attention of the natural philosophers of the period. At Oxford University, between 1247 and 1257, Roger Bacon carried out experiments on lenses and mirrors and described eyeglasses used to aid in reading; these came into widespread use in the following century. An important step along the evolutionary road towards the overhead projector came with the insight in the late 1500s that **systems** of lenses could be used to fashion microscopes and telescopes. We might think of this overhead projector as a marriage between a microscope which produces enlarged images and a *camera obscura* which throws them on to a screen.

Underneath the flat glass plate on which I place the transparency is a composite lens known as a Fresnel lens. Fresnel employed the idea in 1820, although it was developed much earlier, by Buffon in 1748. It concentrates light into a relatively narrow beam. Fresnel's motivation was utterly practical: to make a lens for a lighthouse. A Fresnel lens consists of an assemblage of small thin lenses in place of a single thick lens which would be excessively heavy and difficult to make. Long before their incorporation into the design of overhead projectors, Fresnel lenses were widely used in ships' lanterns, railroad signals and traffic lights.

Overhead projectors need sources of light, as well as lenses. Modern projector lamps frequently consist of quartz-halogen globes, an evolutionary development from tungsten-argon lamps which in turn sprang from Thomas Edison's early work with carbon-filament globes. The search last century for a successful filament material that would not oxidise or evaporate was not an application of any scientific principle: Edison's work reflected patient, methodical trial-and-error. More than a thousand combinations of materials were tried. Technologists often have to work this way.

Projector globes have to be kept cool if they are not to burn out frequently. The technology of the fan is very ancient. The invention of the electric motor last century led to its marriage with the turbine blade, known for centuries in windmills and waterwheels, to give us the electric fan, a kind of windmill in reverse. We may think of the electric motor as an application of physics, especially of Faraday's research on forces on current-carrying wires in magnetic fields. That is true, but it is an oversimplification. In between Faraday's research and the development of the first workable electric motor, many electrical engineering problems had to be overcome that could not be solved simply by applying scientific principles.

Copper is commonly used as material in the coils of electric motors, and in the wiring used to connect them to the power source. It is of course a very ancient material. Copper weapons have been found in Egyptian graves dating back 7000 years, and a couple of hundred kilometres from here, in the Sinai desert, copper was mined and refined almost 5000 years ago. Copper used for electrical purposes is normally 99.92 to

99.96 per cent pure, and is made by electrolytic methods. About 0.03 per cent of oxygen is deliberately left in the copper to maximise its conductivity. The process of electrolytic refining illustrates a clear link between a scientific discovery and a technological outcome, but once again the story is not a simple linear one of science first, technology afterwards. The natural philosophers of the early nineteenth century who investigated the relationship between electric currents and chemical reactions already knew about the differing reactivities of metals. Where did this knowledge come from?

(OHP of copper cup)
Look at this finely crafted, gilded copper cup. It was made in the seventeenth century by a craftsman in a German mining town. It bears a poetic inscription:

Ein Pferd mich vor mit Füssen trat,
da ich noch Eisen ware,
durch zimment wassers baad,
bring ich gut freünd zu baare.

The copper had been made by placing scrap iron in mine waters containing dissolved copper salts. The poem tells the story of the cup's origins. The reference to horses' feet tells us that the scrap iron had come from old horse-shoes. More than a century before scientists discovered current electricity and studied electrolysis reactions, these German miners had already put their knowledge of the displacement of metals to practical use.

The point I want to make here is not simply that the art and the technology preceded the scientific understanding in a chronological sense. I am making a stronger claim: that the technological knowledge is **necessary** for the growth of subsequent scientific understanding. The miners' practical knowledge provided the eighteenth century chemists with the basis for the idea of the affinity table, the forerunner of the electrochemical series. The idea that metals possess different affinities was crucial to the invention of the voltaic cell, and hence to the discovery of current electricity and electrolysis.

It is time to weave the various parts of this story together. Overhead projectors and other artefacts do not emerge simply as a result of their inventors applying scientific knowledge. There is no straightforward linear relationship between science and technology. Copper for ancient weapons and cooking pots, glass for ancient ornaments, windows and containers, fans for personal comfort, mirrors for personal adornment: science and technology always have their roots in practical techniques, in the arts and crafts, in the universal human activities which keep our bodies and souls together.

These thoughts have some educational implications. Science curricula commonly present an idealist view of the roots of science and technology which gives primacy to scientific knowledge. It is time, I believe, to give greater recognition to the materialist view: that the artisan, the artist or the engineer is often the first to become familiar with the properties of materials. The scientist frequently comes later and provides us with theoretical concepts to help us to understand the how and why. This materialist reading of the historical and philosophical roots of technology and science should be given greater prominence. It would help raise the status of technology education so that it can become more widely accepted as an equally valuable contributor to the curriculum.